V

1

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

AD-A243 467

2. REPORT DATE
Fall 1991

3. REPORT TYPE AND DATES COVERED
THESIS/XXXXXXXXXXXXX

4. TITLE AND SUBTITLE
Influence of Knee Joint Extension on Submaximal Oxygen Consumption and Anaerobic Power in Cyclists

5. FUNDING NUMBERS

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

AFIT Student Attending: Colorado State University

8. PERFORMING ORGANIZATION REPORT NUMBER

AFIT/CI/CIA- 91-070

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

AFIT/CI
Wright-Patterson AFB OH 45433-6583

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for Public Release IAW 190-1
Distributed Unlimited
ERNEST A. HAYGOOD, 1st Lt, USAF
Executive Officer

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

14. SUBJECT TERMS

15. NUMBER OF PAGES
47

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

91-17931

THESIS

INFLUENCE OF KNEE JOINT EXTENSION ON SUBMAXIMAL OXYGEN CONSUMPTION AND ANAEROBIC POWER IN CYCLISTS

Submitted by

Jesse Garcia

Department of Exercise and Sport Science

A-1

In partial fulfillment of the requirements

for the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Fall 1991

91 12 13 181

COLORADO STATE UNIVERSITY

June 5, 1991

WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY JESSE GARCIA ENTITLED INFLUENCE OF KNEE JOINT EXTENSION ON SUBMAXIMAL OXYGEN CONSUMPTION AND ANAEROBIC POWER IN CYCLISTS BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

Committee on Graduate Work

Alan Tucker

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Advisor

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ABSTRACT OF THESIS

EFFECT OF KNEE JOINT EXTENSION ON SUBMAXIMAL

OXYGEN CONSUMPTION AND ANAEROBIC POWER IN CYCLISTS

There is a considerable body of research concerning riding position of the cyclist. However, there are few studies which have investigated the effect on performance of pedaling with various amounts of knee joint extension. This study was designed to assess the effect of alterations of maximal knee joint extension on submaximal $\dot{V}O_2$, anaerobic peak power, and anaerobic mean power in cycling.

Eleven amateur male bicycle racers between the ages of 19 and 35 years were selected, for participation in this study. The subjects were randomly assigned to one of four groups. All subjects performed a five minute submaximal exercise test and a Wingate anaerobic power test at maximal knee extensions of 25°, 32°, 39°, (posterior: 155°, 148°, 141°) and the subject's usual knee position. The subjects rode an ergometer which allowed the subjects to maintain their normal riding position as saddle height was altered to position the knee at the test angles. In order to assure a random testing sequence, each group was tested with a different order of presentation of the test positions according to a 4 X 4 Latin Square design.

Analysis of variance (ANOVA) did not reveal significant ($p > .05$) differences in performance among the four test positions. Regression analysis revealed saddle

height to be a poor indicator of the angle of maximal knee joint extension. It was concluded that for male bicycle racers there is no difference in submaximal $\dot{V}O_2$, anaerobic peak power output, or average anaerobic power output when cycling with saddle positions which result in maximal knee joint extensions ranging from 39° to 25° (posterior: 141° to 155°). Therefore, cyclists should feel free to seek a comfortable position within this range. Furthermore, the establishment of a cyclist's saddle height based on knee joint angle may be preferable to basing saddle height on leg length.

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ACKNOWLEDGEMENTS

I would like to express my deepest gratitude and sincere appreciation to those individuals who made this study possible. Drs. James Sockler, Spiros Prassas, and Alan Tucker deserve my thanks for allowing me the opportunity to pursue this study. I especially appreciate the help that Dr. Sockler, my advisor, has given in transforming my idea into a concrete project. His assistance with the statistical analysis was also vital. I wish to thank my wife, Nancy, for her patience and support and my young son Alexander for teaching me the value of questioning the mundane. Finally, I would like to thank the bicycle racers who volunteered to participate in this study. Without their hard work and co-operation this study would not have been possible.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Renewed interest in the sport of bicycling has been accompanied by an increase in research concerning the biomechanics, aerodynamics, and technology of bicycling. New developments in frame materials and geometries, aerodynamic components and apparel, and training methods have emerged (Hopkins & Principe, 1990; Kyle, 1989; Spangler & Hooker, 1990). However, the biomechanical and physiological role of the rider as the power source of the rider-bicycle system remains a given. Recent research has explored alterations in upper body and trunk positioning as means of improving aerodynamic and physiologic efficiency (Kyle, 1989). However, the lower extremities remain the source and the mode of transmission of force to the bicycle drive train and research to date does not indicate the optimal knee joint position for this task.

Researchers, cycling coaches, cyclists, and medical personnel agree on the importance of proper knee joint positioning for efficient injury-free cycling (Gregor & Rugg, 1986, Peifer, 1990; Powell, 1986). Saddle position is the means by which knee motion can be altered. Cycling coaches, cycling authorities, and cyclists themselves also agree that saddle position is the most important dimensional bicycle adjustment (Hodges, 1986; Lemond & Gordis, 1987; Nordeen, 1976). However there is not agreement as to which position is optimal. A plethora of recommendations for proper saddle position can be found in the bicycling press. Research on saddle positioning for maximal aerobic efficiency and power production has been equivocal (Hodges, 1986; Nordeen-Snyder, 1977; Shennum & deVries, 1976; Titlow, Ishee, & Anders, 1986). The angle of the knee at any point in the cycling stroke is a function of saddle height, horizontal saddle position, muscular flexability, crank arm length, shoe/pedal dimensions and type, and ankling technique (Borysewicz, 1985).

This multiplicity of factors may explain the lack of consensus for one "optimal" saddle height which would be suitable for a diversity of cyclists, equipment, and techniques. Since the angle of the knee, specifically the maximum amount of extension, is the primary concern in the adjustment of seat height, this study attempted to relate the effect of knee extension to submaximal oxygen consumption ($\dot{V}O_2$) and power output. Currently, there are no scientifically based guidelines for determining the optimal knee extension for maximal aerobic efficiency and power output while cycling. The utilization of such a standard, in combination with readily available video recording equipment, would allow the adjustment of the bicycle saddle to an appropriate height for any cyclist in spite of differences in body dimensions, equipment, or ankling technique which cannot be taken into account by current saddle height formulas. The determination of the most physiologically an mechanically efficient magnitude of knee joint extension should provide a means for accurate saddle positioning for the racing bicycle as well as for the research bicycle ergometer.

Statement of the Problem

The purpose of this study was to determine the effect of changes in maximal knee joint extension during the cycling stroke upon the aerobic efficiency and power output of the cyclist.

Hypotheses

It was hypothesized that alterations in the angle of maximal knee joint extension in cycling affect the physiological and biomechanical efficiency of the cyclist. The following hypotheses were tested ($p \leq .05$):

1. Changes in the amount of maximal joint knee extension in the cycling stroke would result in changes in oxygen consumption ($\dot{V}O_2$) at a given steady state workload.

2. Changes in the amount of maximal knee joint extension in the cycling stroke would result in changes in anaerobic peak and mean power output.

Delimitations, Limitations, and Assumptions

Delimitations

This investigation was delimited to 11 male amateur bicycle road racers, aged 19 to 35 years, in order to ensure a homogeneous sample representative of the population of bicycle racers. The subjects had sufficient hamstring and calf flexibility to allow proper pedaling in all test positions. Four knee joint angles were tested. Testing was conducted during a non-racing time of year. The test ergometer closely approximated the subject's actual position on a racing bicycle. The saddle fore and aft position and the handlebar height and reach were adjusted so that each subject maintained a consistent upper body posture and positioning over the pedals.

Limitations

Only four knee joint angles were tested. The subjects did not have an extended time period during which to accustom themselves to each position. A random sample of the population of bicycle racers was not possible so this study depended on the representativeness of the volunteer subjects to the population of bicycle racers.

Assumptions

It was assumed that the subjects were highly motivated competitors and performed to the best of their abilities during all tests. Randomization in assignment to experimental groups and the experimental design in sequencing knee positions eliminated bias and learning effects.

Definitions

Bottom Bracket: The portion of the bicycle or ergometer frame which contains the crank and crank bearings. The seat tube and bottom tube attach to the bottom bracket.

Crank Arm: The metal lever which is attached to the crank. The pedal attaches to the distal end of the crank arm.

Handlebar Height: The difference between the saddle top and the handlebar top.

Handlebar Reach: The distance between the handlebar and the front of the saddle.

Knee Angle: In the clinical setting the fully extended knee joint is usually described as 0° flexion and lesser amounts of extension are indicated as degrees of flexion; this system measures the angle between the shank and the continuation of the line of the femur. Another system measures the angle posterior to the knee. In this system full knee extension is labeled as 180°. For clarity, the knee joint angle measurements are indicated in both conventions. The knee angles in this study were determined when the pedal spindle was at the bottom of the stroke. All knee angles were determined dynamically.

Saddle Height: The distance from the top of the saddle to the lower pedal spindle when the crankarms are parallel to the seat tube.

Saddle Horizontal Position: The horizontal distance from the front of the saddle and a verticle line through the center of the bottom bracket.

Test Positions: The knee joint angles (measured at the bottom of the stroke) at which the aerobic and anaerobic tests were performed.

Position 1 = Usual Knee Angle

Position 2 = 25°

Position 3 = 32°

Position 4 = 39°

Usual Knee Angle: The angle of the knee joint when the pedal spindle is at the bottom of the cycling stroke while the subject was riding his own bicycle. No alterations were made to the subjects's bicycle.

CHAPTER II

LITERATURE REVIEW

A review of the literature revealed very little research studying the relationship of knee joint angle at maximal extension in the cycling stroke to performance, physiologic parameters, or injury. While several studies have looked at saddle height in relation to performance, these studies did not address knee position. Considerable investigation of other factors affecting cycling performance, such as pedaling rate and crank arm length, has been performed. There is also no scarcity of recommendations concerning body positioning, equipment, and technique in the popular cycling press.

Studies Specifying Knee Joint Angles

In a study of high school students performing submaximal work on a bicycle ergometer, Titlow et al. (1986) failed to find significant differences in heart rates while pedaling at three different knee joint angles with a workload of 100 W. Studies (Nordeen,1976; Nordeen-Snyder, 1977) involving college females who were not skilled cyclists, indicated that a saddle height which was 100% of the subjects' leg length (as measured from the greater trochanter to the floor) produced the lowest oxygen consumption ($\dot{V}O_2$) at submaximal cycling tests. The workload was 799 kpm/min. An examination of the data reveals that this position resulted in maximal knee joint extension values which ranged from 22.9° in the subject who reached the greatest amount of extension to 46.1° in the subject with the least amount of knee extension (Nordeen, 1976). Apparently, saddle height was not an accurate indicator of the extent of knee extension in this sample of subjects. In a study which examined heart rate and perceived exertion, Mandroukas (1990) concluded that cycling with the knee joint flexed to 55° - 60° was less effective than pedaling with the knee in a more extended position.

Oxygen Consumption and Saddle Height

Shennum and deVries (1976) used saddle heights which ranged from 100% to 112% of leg length (as measured from ischium to the floor) and workloads ranging from 50 to 200 W to conclude that the 100% position required the lowest mean $\dot{V}O_2$ for five experienced cyclists. The authors stated that a laboratory bicycle ergometer was adapted to simulate a racing bicycle but the exact nature of the adaptation was not specified.

National cycling team members were the subjects in a study by Hodges (1986). Saddle heights ranged from 92% to 100% of leg length (as measured from the greater trochanter to the floor) and the findings indicated that at a submaximal workload, $\dot{V}O_2$ was significantly increased at the 99% and 100% positions when compared to the lower positions. Testing was conducted on the subjects' own bicycles.

Power Output

In a study of 100 cyclists with a wide range of cycling experience, Hamley and Thomas (1967) determined that the greatest average power output occurred when the saddle height was positioned at 109% of leg length. They measured leg length as the distance from the pubis symphysis to the floor. Four saddle positions ranging from 105 to 117% of leg length were tested.

Pedaling Rate

There is abundant documentation that pedaling rates of 80 to 110 rpm are the typical cadences of bicycle racers (Borysewicz, 1985; Cavanagh & Sanderson, 1986; Coast, Cox, & Welch, 1986; Coast & Welch, 1985; Hagberg, Mullin, Giese, & Spitznagel, 1981; Hodges, 1986; Seabury, Adams, & Ramey, 1977). In a study which utilized eight pedaling rates and four power outputs, Seabury et al. (1977) concluded that the most efficient pedaling rate increases with power output. At a power output of 326.8 W, 62 rpm was considered optimal. The authors stated that the disparity between this figure and the subjects' usual cadence might have been due to the difference in the weight of the heavy flywheel and crankset of the ergometer and the weight of the wheels and cranksets of racing bicycles.

Hagberg et al. (1981) surmised that bicycle road racers performed most efficiently at an average of 91 rpm when tested on their own bicycles. They also indicated that cadences above 100 rpm were not advantageous for road racers. Patterson, Pearson, and Fisher (1983) conducted a study which demonstrated that there were no significant differences in biomechanical, physiological, or subjective responses to exercise when using heavy or lightweight ergometer flywheels. They also concluded that increasing cadence produced only small increases in $\dot{V}O_2$. They theorized that reduced peripheral muscle fatigue coupled with only small increases in $\dot{V}O_2$ may explain the racing cyclists' preference for higher cadences.

Croisant and Boileau (1984) stated that the efficiency of pedaling is dependent on the combination of rate and load. Coast and Welch (1985) concluded that the optimal cadence increases with increased power output and with increased skill of the cyclist. In a study of trained bicycle racers, Coast, Cox, and Welch (1986) concluded that at a workload of 85% of $\dot{V}O_{2max}$, greatest efficiency occurred at a rate between 60 and 80 rpm and that perceived exertion was lowest at 80 rpm.

Crank Length

The design of the typical racing bicycle dictates a crank length of approximately 170 mm (Whitt and Wilson, 1982), however, within the relatively narrow range of possibilities, cyclists and coaches advocate longer or shorter crank lengths based on rider height and the type of race (Borysewicz, 1985). In tests of power output, Inbar, Dotan, Trousil, and Dvir (1983) established that tests using crank lengths ranging from 125 to 225 mm resulted in mean power and peak power variability of only 0.77% to 1.24% respectively. These observations support those of Whitt and Wilson (1982).

In contrast, kinetic studies of lower extremity biomechanics by Hull and Gonzalez (1988) indicate that pedaling rate as well as crank length affect lower extremity joint moments. Additionally, there is an interaction between pedaling rate and crank length which results in an optimal pedaling rate for each crank length. It was also noted that optimal crank arm length increases with the height of the cyclist and that optimal cadence decreases with increasing height.

Muscle length-tension relationship

The total tension developed by a muscle is the sum of the active tension generated by the contracting fibers plus the passive tension of the non-contracting muscle elements. The magnitude of the contributions of active and passive tensions to the total tension developed is determined by the length of the muscle (Ganong, 1989). The optimal length for development of maximal active tension is that length which allows the greatest actin and myosin cross bridge formation (Guyton, 1977). This length is termed the resting length of the muscle (Ganong, 1989). The length at which total tension is greatest is 20% greater than the resting length (Astrand & Rodahl, 1977). Alterations of the cycling position which would optimize the muscle length of the lower extremities could improve cycling performance (Gregor & Rugg, 1986).

Muscle Force-Velocity Relationship

The tension that can be developed by a muscle is inversely related to the speed of concentric contraction (Astrand & Rodahl, 1977; Gregor & Rugg, 1986). As the speed of contraction increases, there is less opportunity for actin-myosin crossbridge formation and thus less tension can be generated (Gregor & Rugg, 1986). Astrand and Rodahl (1977) stated that the greatest power development with a concentric contraction is at a velocity of contraction of 25% to 30% of maximum.

Conclusion

It is evident that bicycle propulsion involves many factors and relationships many of which have not yet been fully explored. Alterations in positioning result in changes of muscle length, strength of muscle contraction leverage, and velocity of joint motion. Changes in pedaling rate affect the pattern of muscular activity while changes in saddle height influence the magnitude of knee loads (Ericson, 1986). It has been shown that handlebar position, and thereby trunk position, can affect pulmonary function and oxygen uptake (Faria, 1984). Footwear has been shown to have an effect on the energy cost of cycling (Anderson & Sockler, 1990; Davis & Hull, 1981) as has pedal platform height (Hull & Gonzalez, 1990). When performing studies involving changes in cycling position, one must be aware of the scope of factors influencing the efficiency of cycling and attempt to control for these variables as effectively as possible. Selection of equipment, position, and technique that closely match those of the subject population is very important in order to perform meaningful cycling research.

CHAPTER III

METHODS AND PROCEDURES

Approval for this study was obtained from the Colorado State University Human Research Committee (Appendix A) prior to beginning this study. All subjects were informed of the protocol, risks, and benefits prior to signing the informed consent form (Appendix B). Each subject completed a medical questionnaire (Appendix C) in order to ensure freedom from any disease condition which could be exacerbated by participation in this study or which could jeopardize the validity of the results. Each subject was advised of his right to withdraw from the study at any time.

Subject Selection

The subjects for this study were 11 trained, male amateur bicycle racers between the ages of 19 and 35 years. All subjects had at least one year of competitive cycling, had competed the previous season, and were in training at the time of this study. The subjects were free of cardiovascular or pulmonary disease; additionally, the subjects were also free of any orthopedic condition which would limit performance of the required activities. All subjects had sufficient hamstring and calf flexibility to allow proper pedaling in all test positions (Feingold, 1986).

Research Methods

Each subject was instructed to avoid strenuous exercise for 24 hours and to refrain from eating for two hours prior to the test session. The subjects were randomly assigned to one of four groups in a 4 x 4 Latin Square design. Each group performed submaximal $\dot{V}O_2$ and anaerobic power output tests at maximal knee extensions of 25°, 32°, 39° (posterior: 155°, 148°, 141°), and the subject's usual knee position. The order of knee positions was different for each group (Table 1). For each test position, the power output test followed the aerobic test after a 15 minute recovery period. There was a 20 minute period between test sessions for the four test positions. A bicycle ergometer designed to simulate the positioning of a racing bicycle was utilized for the testing. Saddle fore and aft location and handlebar position were adjusted as needed to maintain the knee in alignment with the pedal spindle and to maintain the subject's usual trunk and upper extremity position. Prior to testing, anthropometric measurements, subjects' bicycle measurements, and measurements of the subjects' usual riding positions were recorded. Testing was performed in the Human Performance Laboratory at Colorado State University.

Test positions

In order to determine the amount of knee extension typical of high level bicycle racers, video tapes of elite cyclists were analyzed. Measurement of the maximal amount of knee extension of 45 international amateur and professional bicycle racers yielded a mean angle of 32° (posterior: 148°) with a standard deviation of 7°. Based

Table 1. Order of Test Positions by Group

GROUP	TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 4
1	Position 1	Position 2	Position 3	Position 4
2	Position 2	Position 3	Position 4	Position 1
3	Position 3	Position 4	Position 1	Position 2
4	Position 4	Position 1	Position 2	Position 3

Position 1 = Usual knee extension, Position 2 = 25° (posterior: 155°), Position 3 = 32° (posterior: 148°), Position 4 = 39° (posterior: 141°)

on these findings, the positions of 25°, 32°, and 39° were selected as positions for testing. In addition, each subject was also tested at his usual degree of knee joint extension. The subjects' usual positions were included because there is speculation that there may be enhanced efficiency at an athlete's usual training position (Campbell, 1986; Cavanaugh & Williams, 1982; Hodges, 1986). The subject's usual position was designated as Test Position 1, the 25° position was Test Position 2, the 32° position was Test Position 3, and the 39° position was Test Position 4.

Measurements

Flexibility testing was performed prior to exercise testing. Hamstring flexibility was tested in the supine position with an acceptable measurement being 20° or less from full knee extension (Davies, 1984; Feingold, 1986). Gastrocnemius flexibility was assessed in the supine position with the knee straight. The subtalar joint was maintained in the neutral position while the ankle was dorsiflexed to at least 0° of dorsiflexion (Davies, 1984). The height and weight of each subject was then recorded. With the subject standing in bare feet, with feet together, the leg length from the greater trochanter of the left hip along the lower extremity through the lateral malleolus to the floor was measured and recorded.

The subject's bicycle was then positioned on a training stand and the following distances were measured and recorded:

1. Saddle Height from the top of the saddle to the pedal spindle. The crank arm was held in line with the seat tube.

2. Height of the saddle above the top tube of the bicycle.
3. Height of the handlebar above the top tube of the bicycle.
4. The difference between distance 2 and distance 3.
5. Distance from the front of the saddle to the handlebar.
6. Horizontal distance between the pedal spindle and the saddle center. The crank arm is in the forward horizontal position for this measurement.

These measurements were used to facilitate the adjustment of the ergometer to simulate the position of the subject's bicycle and to ensure the maintenance of the subject's normal body position as the saddle height was altered to produce the desired test positions.

Each subject was then videotaped (Panasonic VHS camcorder) at a shutter speed of 1/250 sec while riding his bicycle, which was still mounted to the training stand. The position of the knee at bottom dead center (BDC) was determined by standard goniometric technique (Esch & Lepley, 1971) by measuring the image on a large screen monitor. By convention (Esch & Lepley, 1971; Winter, 1979), the fully extended knee is described as 0° flexion and lesser amounts of extension are indicated as degrees of flexion; this system measures the angle between the shank and the continuation of the line of the femur. There is another system which measures the angle posterior to the knee. In this system full knee extension is labeled as 180°. For clarity, the knee angle measurements using this convention are also indicated.

The knee angle for each test position was verified in the same manner prior to performing testing. Saddle position was raised or lowered as necessary to place the knee in the desired test position. Adjustments to the handlebar position and saddle horizontal location were made as needed to maintain the knee in alignment with the pedal spindle and to maintain the subject's usual trunk and upper extremity positions.

Submaximal Oxygen Consumption Tests

For each test position, a test of submaximal intensity was performed on a Tunturi bicycle ergometer (Professional Ergoracer). After performing adequate stretching and warmup riding, each subject rode the bicycle ergometer at 90 rpm, at a resistance of 18 Newton-meters (Nm) for a workload of 283 W for a period of five minutes. The ergometer has a pedalling speed indicator and each subject was instructed to pedal in his normal manner while maintaining a 90 rpm cadence. To assist in maintaining the desired pedalling speed, a musical tape synchronized to 90 rpm (Medical & Sports Music Institute) was played during all submaximal tests. Additionally, a fan was directed at the subjects to prevent overheating and to simulate the wind sensation of actual bicycling.

Computerized on-line open circuit indirect calorimetry (Medtronics 2900 Energy Measurement System) was used to determine $\dot{V}O_2$. A modified 3-lead (CM-5) ECG electrode configuration and Roche ECG monitor (model 105) was connected to the system and provided continuous heart rate display. The first three minutes of the test were utilized to allow the subject to achieve a steady state condition. The mean $\dot{V}O_2$ for the last two minutes of the test were used for data analysis.

Power Output Test

The Wingate test for anaerobic power output was used to determine peak and mean power output at each test position (Adams, 1990; Dotan & Bar-Or, 1983; Inbar et al., 1983; Bar-Or, 1987; Patton and Duggan, 1987). At each knee position, the Wingate test was performed 15 minutes after the submaximal aerobic test. A resistive force of 0.075 kp/kg of body weight was set (Adams, 1990; Bar-Or, 1983) and the subjects pedalled at maximal effort for 30 seconds. A magnetic sensor attached to the ergometer sensed crank rotations and this was recorded on the graph paper of a flatbed chart recorder (Kipp & Zonen Model BD41).

Peak anaerobic power was calculated by counting the greatest number of crank rotations within a five second period and entering this number into the following formula (Adams, 1990):

Peak Power (kgm-5sec) = R x D x F

where: R = the number of crank rotations in five seconds

D = the distance a point on the circumference of the flywheel travels per one crank revolution (6.28 m for the Tunturi)

F = the force in kg

Multiply kgm-5sec x 2 to convert to watts.

Mean anaerobic power for the 30 second test, also called anaerobic capacity (AnC) (Adams, 1990; Bar-Or, 1983) was calculated by counting the total number of crank revolutions and entering this number into the following formula:

AnC (kgm-30sec) = R x D x F

where: R = the number of crank rotations in 30 seconds

D = the distance a point on the circumference of the flywheel travels per one crank revolution (6.28 m for the Tunturi)

F = the force in kg

Divide kgm-30sec by 2 to convert to watts.

Data Analysis

Data were reduced by the Colorado State University Statistics Laboratory, utilizing SAS release 6.04 (SAS Institute Inc.). A Latin Square analysis of variance (ANOVA) procedure was performed on group, position, and trial order for each of the dependent variables which were $\dot{V}O_2$, peak power, and mean power. The Student-Newman-Keuls test was used for post hoc analysis. In addition, the linear regression procedure was used to derive an equation to predict knee angle from saddle height. The level of significance for all analyses was set at $p \leq .05$.

CHAPTER IV

RESULTS AND DISCUSSION

Results

All 11 subjects completed the five minute submaximal test and the 30 second Wingate anaerobic power test at each of the four test positions. All subjects attained a steady state condition during the submaximal exercise tests and rated the submaximal exercise tests as being moderately easy. No subject felt fatigued as the test session progressed. The characteristics of the subjects are displayed in Table 2.

The Latin Square ANOVAs of the means of the three dependent variables ($\dot{V}O_2$, peak power, and AnC) (Table 3, Figures 1, 2, & 3) against group, position, and trial order of position revealed a significant ($p \leq .05$) group effect. The test position and trial order of presentation were not significant for any of the three dependent variables; however, test position vs. $\dot{V}O_2$ had a p-value of 0.1085. Because subjects were randomly assigned to the groups and the trial effect proved non-significant, the group effects can be attributed to the individual variability of the subjects rather than to an effect based upon grouping. The linear regression procedure produced the following equation to predict knee angle from the saddle height (expressed as saddle height divided by trochanteric leg length x 100) with a standard error of 20.85, R^2 of 0.285, and $p=.0002$:

Knee angle (degrees of flexion) = 117.45 - (0.85924 x saddle height)

Table 2. Subject Characteristics

	Age (yr)	Height (cm)	Weight (kg)	Years racing
GROUP 1 (n=3)	27.3 ± 5.1	175.3 ± 3.9	72.3 ± 8.4	7.0 ± 4.4
GROUP 2 (n=3)	21.3 ± 2.2	180.3 ± 2.2	75.7 ± 3.5	1.7 ± 1.0
GROUP 3 (n=2)	23.5 ± 3.7	176.5 ± 3.7	69.0 ± 1.1	4.5 ± 1.6
GROUP 4 (n=3)	27.7 ± 6.0	177.0 ± 3.1	72.3 ± 5.4	5.0 ± 3.0
TOTAL SAMPLE (n=11)	25.1 ± 5.2	177.0 ± 3.7	73.0 ± 5.8	4.5 ± 3.5

Note: All values are mean ± Standard Deviation. No significant ($p > .05$) differences among group means.

Table 3. Comparison of $\dot{V}O_2$, Peak Anaerobic Power, and Mean Anaerobic Power for the Four Test Positions.

VARIABLE	POSITION 1	POSITION 2	POSITION 3	POSITION 4
$\dot{V}O_2$ ($ML \cdot min^{-1}$)	2924 ± 70	2900 ± 75	2835 ± 86	2827 ± 90
Peak Anaerobic Power (W)	652 ± 27	627 ± 30	658 ± 25	645 ± 25
Mean Anaerobic Power (W)	587 ± 24	565 ± 24	589 ± 24	580 ± 19

Note: Position 1 = Usual knee extension, Position 2 = 25° (posterior: 155°), Position 3 = 32° (posterior: 148°), Position 4 = 39° (posterior: 141°). All values are mean ± Standard Error of the Mean. No significant ($p > .05$) differences among group means.

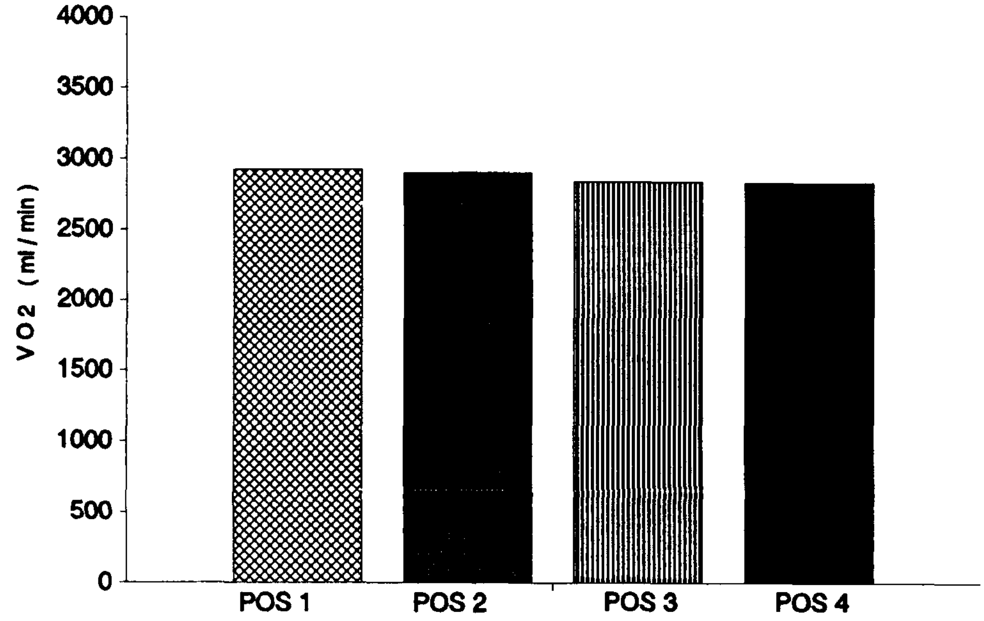

Figure 1. Comparison of Mean $\dot{V}O_2$ at the Four Test Positions.
Position 1 = Usual knee extension, Position 2 = 25°(posterior: 155°), Position 3 = 32° (posterior: 148°), Position 4 = 39° (posterior: 141°)

Note: Standard Errors are too small to be discerned on graph.

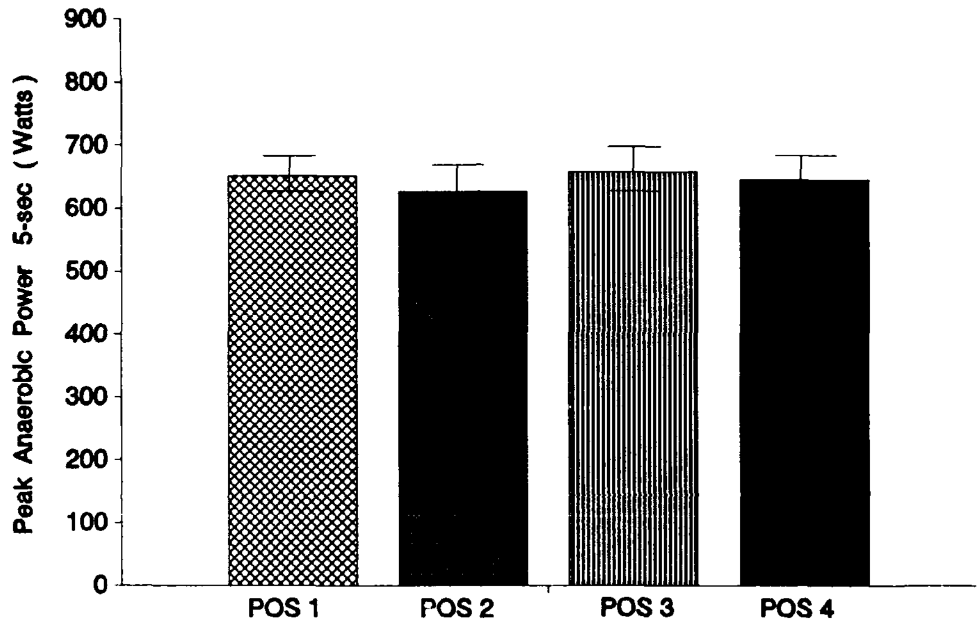

Figure 2. Comparison of Peak Anaerobic Power at the Four Test Positions. Means ± Standard Error
Position 1 = Usual knee extension, Position 2 = 25° (posterior: 155°), Position 3 = 32° (posterior: 148°), Position 4 = 39° (posterior: 141°)

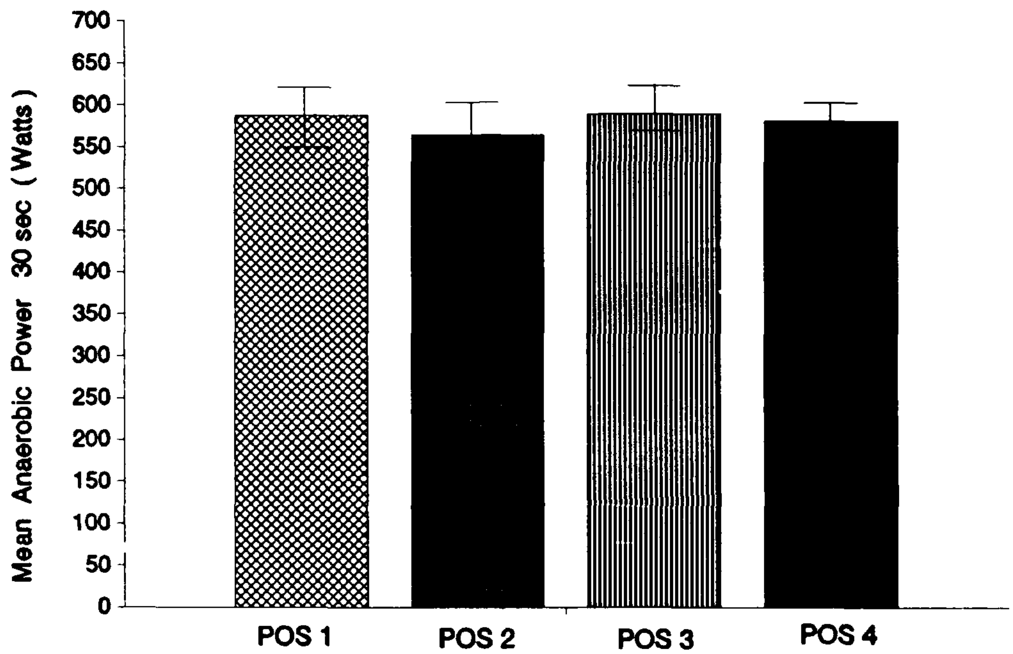

Figure 3. Comparison of Mean Anaerobic Power at the Four Test Positions.
Means ± Standard Error
Position 1 = Usual knee extension, Position 2 = 25° (posterior: 155°), Position 3 = 32° (posterior: 148°), Position 4 = 39° (posterior: 141°)

Discussion

Although there is a paucity of research directly relating knee angle to performance or efficiency in cycling, relevant information can be obtained from studies which relate saddle height to $\dot{V}O_2$ or power production. Hamley and Thomas (1967) performed one of the earliest studies involving saddle height and expressed leg length as the distance from the pubis to the floor. Most of the subsequent researchers have normalized leg length to the method used in this earlier study. Shennum and deVries (1976) reported a direct relationship between saddle height and $\dot{V}O_2$, with the lowest of their test positions resulting in the lowest $\dot{V}O_2$. Using their correction factor, this position equated to 105% of pubis to floor leg length. A study of nine untrained females concluded that a saddle height 100% of leg length as measured from the greater trochanter to the floor required the least $\dot{V}O_2$. This position was estimated to be equal to 107% of the pubic leg length (Nordeen, 1976; Nordeen-Snyder, 1977). Hodges (1986) indicated that a saddle height 96% of trochanteric leg length was most efficient and calculated that the position was equal to 106% of pubic leg length.

While this study did not demonstrate significant differences of mean $\dot{V}O_2$ among the four test positions, the raw data indicated lower $\dot{V}O_2$ at the positions of lesser knee extension, 32° and 39°. The mean saddle heights for these positions were 99% and 96% of trochanteric leg length, respectively. Using Hodges' (1986) correction factor, these positions correspond to 110% and 106% of pubic leg length. This appears to corroborate the earlier studies which did not directly address knee joint angle. Another consistency between this study and the previous studies was the size of the differences in mean $\dot{V}O_2$ with respect to change in position. All of these studies demonstrate a flat relationship between saddle height and $\dot{V}O_2$ except at the highest and lowest positions which demonstrate significant differences between each other. The current study produced a non-significant 100 ml difference between the positions with the highest and lowest $\dot{V}O_2$. This amount of difference was also typical of the other studies.

There were no differences among test positions for either peak anaerobic power or mean anaerobic power. These findings are contrary to the observations of Hamley and Thomas (1967) and to the recommendations of many cycling coaches (Borysewicz, 1985; C..r. .ell, 1986; Hodges, 1986) who believe that a higher saddle position facilitates power generation. These findings, however, concur with a recent study (Yoshihuku & Herzog, 1990) which observed only minimal changes in power output while varying the saddle height in a 24cm range from the optimal position calculated by their biomechanical model. Desipres (1974) concluded that there was no significant alteration of electromyographic muscle activity between saddle heights of 95 and 105% of pubic leg length.

The analysis of the knee joint angles of elite cyclists which was used to determine the test angles for this study revealed a mean position of 32° (posterior: 141°) ± 7°. The mean usual position for the subjects in the current study was 32.6° (posterior: 147.4°) ± 6°. The close similarity of the riding positions adopted by these groups of competitive cyclists supports the theory that experienced athletes develop a subjective understanding of the factors affecting performance in their sport and will self optimize

(Cavanaugh & Kram, 1985; Cavanaugh & Sanderson, 1986; Cavanaugh & Williams, 1982; Hodges, 1986). In the current study, five subjects had a usual knee joint angles of 32° (posterior: 141°) and an additional four subjects indicated that they felt most comfortable in the 32° position. For all but one subject, lowest $\dot{V}O_2$ values occurred at either the 32° or 39°. The results of this study confirm the observations of Hodges (1986) that there is a wide range of saddle heights which allow efficient oxygen consumption. Additionally, this study suggests that a knee position of 32° may be a logical starting point for individual cyclists or subsequent studies searching for optimal positions for individual cyclists.

It is an acknowledged that the amount of knee extension available at a given saddle height is influenced by a variety of factors, including flexibility, shoes, pedals, and horizontal saddle position (Borysewicz, 1985; Gregor & Rugg, 1986; Hodges, 1986; Hull & Gonzales, 1990). The regression of knee joint angle on saddle height performed in this study, indicated that, while saddle height is an indicator of knee angle, it can account for only 28.5% of the variability of knee joint angle in this sample. The subjects in the Nordeen (1976) study exhibited an even larger amount of variability in knee angles for a given saddle height. These findings support the assertion that saddle height is not an a sufficiently accurate indicator of knee joint angle in cycling.

It is possible that studies to date have not been sophisticated enough to elucidate the subtle mechanical and physiological complexities of the rider-bicycle system. Problems with the studies have included small sample sizes, equipment and techniques which were different from those normally used by cyclists, and failure to maintain the subjects' normal upper body and horizontal leg positions as the vertical position of the legs was altered. Except for the study by Hamley and Thomas (1967), all of the previously cited studies have utilized sample sizes of 16 or less.

Recent developments in aerodynamic cycling equipment attest to the fact that 1-3% improvements in performance have an immense impact on performance in competition (Hagberg & McCole, 1990; Kyle, 1988; Kyle, 1989; Kyle, 1990). In a bicycle race, the difference between first and last place can be a 1-2% difference in time (Hagberg and McCole, 1990). Using the predictive model of van Ingen Schenau (1988), a position which was 100ml $\dot{V}O_2$ more efficient at the workload used in this study would result in a bicycle speed of 34 km per hour (21.1 mph) compared to 33.4 km per hour (20.75 mph) at the less efficient position. These values would assume a 75 kg cyclist, 1.80 m tall, riding a 9 kg bicycle in a standard racing posture, and flat windless conditions. This 0.6 km per hour (0.37 mph) difference translates to 4.8 minutes over a distance of 160 km (100 miles) which is typical of a bicycle road race. It is apparent that studies with adequate sample size and appropriate design are necessary when attempting to characterize performance changes of small magnitude which can prove to be of great practical importance.

The results of this study indicate that for male bicycle racers there is no difference in submaximal $\dot{V}O_2$, anaerobic peak power output, or mean anaerobic power output when cycling with saddle positions which result in maximal knee joint extension ranging from 39° to 25° (posterior: 141° to 155°). Therefore, cyclists should feel free to alter their position within this range in search of a permanent position which feels most comfortable. Based on the mean position of the subjects of this study and the preliminary study to determine test positions, 32° (posterior: 148°) may be a prudent starting point when seeking this optimal position.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The purpose of this study was to determine the effect of varying maximal knee joint extension on submaximal $\dot{V}O_2$, anaerobic peak power, and anaerobic mean power in cycling. Following approval of the study by the Colorado State University Human Research Committee, 11 males between the ages of 19 and 35 years were selected for participation in this study. The criteria for subject selection required all subjects to have raced during the previous season and to have been in training at the time the study was conducted.

After selection, the subjects were randomly assigned to one of four groups. All subjects performed a five minute submaximal exercise test and a Wingate anaerobic power test at maximal knee extensions of 25°, 32°, 39°, (posterior: 155°, 148°, 141°) and the subject's usual knee position. Each group was tested with a different order of presentation of the test positions according to a 4 X 4 Latin Square design in order to assure a random testing sequence.

ANOVAs were performed to determine the effects of saddle position, group, and order of presentation on $\dot{V}O_2$, peak power, and mean power. For each of the dependent variables, there were no significant differences among the means based on test position or order of presentation of test position. There was a significant ($p < .05$)

group effect for each of the three dependent variables. However, since there was random assignment to the groups and the order of test position presentation was non-significant ($p > .05$), this finding indicated a high degree of difference among the individual subjects rather than a true group effect.

Conclusions

It was concluded that for male bicycle racers there is no difference in submaximal $\dot{V}O_2$, anaerobic peak power output, or mean anaerobic power output when cycling with saddle positions which result in maximal knee extensions ranging from 39° to 25° (posterior: 141° to 155°). Therefore, cyclists should feel free to seek a comfortable position within this range. Furthermore, the establishment of a cyclist's saddle height based on knee angle may be preferable to basing saddle height on leg length. Based on the mean position of the subjects of this study and the preliminary study to determine test positions, a 32° (posterior: 148°) knee joint angle may be prudent starting point when seeking this optimal position.

Recommendations

Further research in the following areas is suggested:

1. Similar studies should employ a large number of subjects of a similar skill level in order to minimize the effects of individual subject variability.
2. Similar studies should be conducted utilizing an ergometer which can more closely simulate the position of a road bicycle including interchangeable crank

arms and pedals. This would allow each subject to use the crank arm length and pedal type that would normally be used in actual training and competition.

3. Similar studies should be conducted using subject samples from different populations such as recreational cyclists, time trialists, mountain bikers, and track cyclists. This would allow determination of optimal positioning for various populations of cyclists.
4. Similar studies should utilize a more sophisticated crank rotation detection system for the Wingate anaerobic power test. The system should include multiple sensors and interface to a computer in order to increase sensitivity to fractions of rotations.
5. Additional studies are required to further define the relationship between saddle height and knee angle.

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APPENDICES

APPENDIX A

PROJECT APPROVAL FORM

LAST NAME OF PI	
SOCKLER	
FILE NO.	DATE SUBMITTED
90-155H	1/15/91
ENTERED TO RECORD	
COORDINATOR S. Netzkoff	
DATE 3/1/91	

COLORADO STATE UNIVERSITY

Human Research Committee

PROJECT APPROVAL FORM

Project Title: The Relationship of Knee Extension to Aerobic Efficiency and Power Output in Cycling.

Principal Investigator: Dr. James M. Sockler

Co-Investigator: Jesse Garcia

Department: Exercise and Sport Science

Funding Agency: None

Funding Agency Deadline Date: N/A

Date of Project Initiation: January 2, 1991

The above project was examined by the Human Research Committee on 3/1/91 (Date) with the following recommendation:

- [ ] Project approved with no conditions.
- [x] Project approved with the condition that an approved consent form must be used.
- [ ] Project conditionally approved if the following conditions are met:

____

____

____

____

Mary Harris

Chairman

Human Research Committee

3/1/91

Date

APPENDIX B

SUBJECT INFORMATION/CONSENT FORMS

COLORADO STATE UNIVERSITY

Subject Information Sheet

Project Title: The relationship of knee extension to aerobic efficiency and power output in cycling.

Principal Investigator: James M. Sockler

Co-Investigator: Jesse Garcia

Contact Person and phone number for questions/problems: Jesse Garcia
(303) 482-6379

Objectives/Purposes of Research:

This research will test the hypothesis that altering the amount of knee extension available in the cycling stroke will affect aerobic efficiency and power generation. Currently there is no published research which directly links knee position to aerobic efficiency or power output.

Procedures/Methods to be Used:

1. You will be randomly assigned to a test group. The order of the test position will be different for each group. However, all groups will be tested at each of the four test positions.

2. Prior to testing, you will be videotaped riding your own bike on a wind-trainer in order to determine your usual riding position. You will use your usual riding shoes and pedals throughout the testing.

3. Testing will be performed on a Tunturi Ergoracer bicycle ergometer which allows adequate adjustments to maintain your normal riding position as the amount of knee extension is varied for each test position. Maximal knee extension for each test position will be determined by measuring the knee angle off videotape recorded by video equipment.

4. Four test positions will be used.

5. The aerobic test will be a sub-maximal ride of five minutes at a moderate resistance. You will be breathing into a mouthpiece which will collect expired air for gas analysis and oxygen consumption ($\dot{V}O_2$) determination.

This will be done for each of the four test positions.

6. The anaerobic power test is called the Wingate test. It consists of maximal pedalling against a heavier resistance for 30 seconds. A counter will count the number of pedal revolutions and this will be used to calculate power production. This will be done for each of the four positions.

Risks:

As with any physical activity, there is a slight risk of musculoskeletal injury. However, since the tests are of short duration and low intensity, there will be adequate warm up, and hamstring and calf flexibility will be checked prior to exercise testing, this risk should be minimal.

Assurance of Confidentiality:

Your name will not be used in any paper or report concerning this research. You will be assigned an I.D. number and this number, instead of your name, will appear on data sheets. Video tapes will be erased when the study is completed.

I agree that the subject has the right to terminate participation in this research project at any time.

Investigator

Date

COLORADO STATE UNIVERSITY

Consent to Serve as a Subject in Research

I,____(print name), consent to serve as a subject in the research investigation entitled: The relationship of knee extension to aerobic efficiency and power output in cycling.

The nature and general purpose of the experimental procedure and the risks have been made known to me by Jesse Garcia.

He is authorized to proceed on the understanding that I may terminate my service as a subject in this research at any time I so desire.

I understand that as with any physical activity, there is a slight risk of musculoskeletal injury.

I understand that it is not possible to identify all potential risks in an experimental procedure, but I believe that reasonable safeguards have been taken to minimize both the known and the potential, but unknown, risks.

I will be videotaped riding in order to determine my usual riding position. Video tapes will be erased when the study is completed.

Signed ____

Subject

Date

If a subject is injured in the course of the research investigation and he/she contends that Colorado State University or an employee thereof is at fault for the injury, the subject must file a claim within 180 days of the date of the injury with the State Attorney General and the State Board of Agriculture. The University's legal and financial responsibility, if any, for such injuries is controlled by state law. Your claim will be referred to the Risk Management Liaison Office for review, and you should direct your inquiries to that office (303/491-5257). The University cannot otherwise compensate subjects for their injuries, and subjects must depend on their own health and disability insurance for compensation for injuries sustained in the course of the research investigations which are not the fault of CSU or its employees.

APPENDIX C

MEDICAL QUESTIONNAIRE

MEDICAL INFORMATION AND HISTORY

NAME:____
Last First Middle Init

AGE:__________ DATE:________________________

Please check the **YES** or **NO** box as appropriate for each question.

If you check **YES** for any question, provide an explanation in the space provide at the bottom of the form.

If you have answered **YES** to more than one question please write the number of the question in front of your explanation.

		NO	YES
1	Are you currently under the care of a physician?		
2	Are you currently taking medications?		
3	Do you have any injuries that could affect your physical performance?		
4	Have you had any surgical operations?		
5	Do you wear an ankle, knee, or back brace?		
6	Do you have any problems with your heart, lungs, or circulation?		
7	Have you ever fainted while exercising?		
8	Do you have respiratory problems? (asthma, bronchitis, etc.)		
9	Do you have any medical problems?		
10	Are you currently exercising at least twice a week?		

Please explain any **YES** answers here. (Use the other side of this form if necessary)

Are you a USCF licensed racer? If so what category?

Are you a professional bicycle racer? How long?

Are you a triathlete, biathelete, Amateur, Professional? (circle those that apply)

How long have you been cycling seriously?

When did you start competive cycling?

What types of events (involving cycling) do you compete in?

Do you plan to race this season?

Are you currently in training?